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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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HIGH-SPEED WIND-TUNNEL TESTS OF AN NACA 0009-64 AIRFOIL

HAVING A 33.4-PERCENT-CHORD FLAP WITH AN OVERHANG

20.1 PERCENT OF THE FLAP CHORD

By David B. Stevenson and Alfred A. Adler

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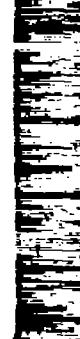
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SUMMARY

Tests were conducted to investigate the effects of compressibility on a 5-inch-chord NACA 0009-64 airfoil section having a 33.4-percent-chord flap with a nose overhang of 20.1 percent of the flap chord and a 0.017-percent-chord unsealed gap. Airfoil lift and pitching moment and flap hinge moment were obtained over an angle-of-attack range of $6°$ and a flap-angle range of $16°$ from a Mach number of 0.4 to the maximum (choking) Mach number that could be obtained for each configuration.

The results showed that, in general, the flap effectiveness decreased with an increase in Mach number. The rate of change of hinge-moment coefficient with both angle of attack and flap deflection $(\partial c_h/\partial \alpha)_\delta$ and $(\partial c_h/\partial \delta)_\alpha$ became more positive with increase in Mach number in the subcritical speed range. The forces and moments caused by deflection of the flap changed abruptly with a change in Mach number in the supercritical speed range.

In general, the flap effectiveness was greater throughout the speed range and the variation in $(\partial c_h/\partial \alpha)_\delta$ and $(\partial c_h/\partial \delta)_\alpha$ with Mach number was less for the NACA 0009-64 airfoil than for a similarly flapped airfoil of NACA 16-009 section previously tested.

The possibility that the trailing-edge angle may be used to control the variation of $(\partial c_h/\partial \delta)_\alpha$ or $(\partial c_h/\partial \alpha)_\delta$ with Mach number is shown.

INTRODUCTION

Flight and wind-tunnel studies have shown that compressibility will have serious adverse effects on the characteristics of the

usual flap type control surface. In order to investigate these
effects two flapped airfoils were tested in the Langley 24-inch
high-speed tunnel. Tests of the first airfoil, an NACA 16-009,
were reported in reference 1. The results of the tests of the
second airfoil, an NACA 0009-64, are given herein.

SYMBOLS

M stream Mach number

c_l airfoil section lift coefficient

$c_{m_c/4}$ airfoil section pitching-moment coefficient about the
quarter-chord point

c_h flap section hinge-moment coefficient; based on c_f

δ flap deflection; negative deflection is upward

α angle of attack

ϕ trailing-edge angle

R radius

c_f flap chord behind the hinge line

c chord of airfoil with 0 flap deflection

When α, δ, and c_l are used as subscripts outside the
parentheses, they signify that the quantity is held constant.

APPARATUS AND TESTS

The tests were conducted in the Langley 24-inch high-speed
tunnel, which is described in reference 2. Recent modification
to this tunnel, which reduced the model span exposed to the air
stream from 24 to 18 inches (fig. 1), is described in reference 3.

The model spanned the test section, passing through holes in
end plates in the tunnel walls. (See fig. 1.) These holes were
of the same shape as the airfoil profile but were slightly larger.
This arrangement approximated two-dimensional flow; hence, the

forces and moments obtained are essentially section characteristics.
The model was a symmetrical airfoil made of steel with an NACA
0009-64 airfoil profile modified to have a 33.4-percent-chord flap
with an overhang of 20.1 percent of the flap chord. The 0.017c gap
was unsealed. A cross section of the model is shown as figure 2.
The ordinates, except for the part of the airfoil affected by the
flap nose and the gap, may be obtained from reference 4.

Airfoil lift and pitching moment were obtained by means of a
spring-type balance similar to that described in reference 5. Flap
hinge moments were measured by means of an electrical strain-gage
system mounted on the balance.

The forces and moments were measured over an angle-of-attack
range extending from -4° to 2° and a flap-deflection range from
-6.1° to 9.9°.

The Mach number range for which the tests were made extended
approximately from 0.40 to 0.85, corresponding to Reynolds numbers
from 1,100,000 to 1,800,000.

FACTORS AFFECTING TEST RESULTS

Tunnel-Wall Effect

As was pointed out in reference 1, tunnel-wall corrections in
the subcritical speed range for a low ratio of model to tunnel size
such as existed in the present tests are small. No corrections
have yet been determined for the supercritical speed range. For
these reasons, no tunnel-wall corrections have been made to the
force-test data presented herein. Serious constriction effects do
occur, however, near the limiting or choking Mach number (reference 3).
The onset of these effects was indicated to occur at Mach numbers
about 0.02 to 0.03 below the choking Mach number by surveys of
static pressure along the tunnel wall similar to those of reference 3.
The results presented are, therefore, questionable in this speed range.
In general, the highest Mach number for each configuration shown in
the figures corresponds to the choking condition.

End-Gap Effects

During these tests, leakage occurred between the test section
and the surrounding test chamber through the end-plate gaps at the
junction between the model and the tunnel wall. The effect of
this leakage upon lift and moment coefficient is shown in reference 2
by a comparison of force-test data with end-plate gaps and essentially
two-dimensional pressure-distribution data obtained in the
Langley 24-inch high-speed tunnel. Although the absolute values

obtained by the two methods differ to some extent, the results are
in agreement as regards the effects of compressibility and therefore
no correction for end leakage has been applied—to the data presented
herein. The effect of end gap on lift—curve slope is small since
the effective aspect ratio of the model always remains above 20.
The effects of end gap on hinge moments have been determined to be
negligible.

Humidity Effects

At the higher tunnel speeds the relative humidity of the
atmosphere, from which the air in the tunnel is drawn (reference 1),
was found to affect the lift and moments under certain conditions.
However, a value of relative humidity has been determined below
which no measureable effects exist. The high—speed data contained
herein were obtained with relative humidities less than this value.

RESULTS AND DISCUSSION

Lift

The effects of compressibility on the lift coefficient for
constant angular conditions are shown in figure 3. The variation
of lift coefficient with angle of attack and with flap deflection
are presented in figures 4 and 5, respectively. The nonlinearity
of the curves shown for low Mach numbers in figure 5 is essentially
an increase in $dC_L/d\delta$ in the small flap—angle range between 3°
and 4°, indicating an improved flow over the airfoil in this angular
range. This improvement seems to be confined to the rear portion of
the airfoil as indicated by the pitching—moment and hinge—moment
data in this range. The nonlinearity cannot be attributed to
inaccuracy in force measurements or in angular settings.

In figure 4, the decrease in the slope of the lift curves
beyond an angle of attack of about -2.5° at Mach numbers of 0.775
or more indicates the effect of compressibility on separation of
the air flow over the airfoil. Similarly, in figure 5 the slope
of the curve of lift against flap deflection decreases above a
Mach number of 0.75 for flap angles from $\pm 4^\circ$ to $\pm 6^\circ$. At flap
angles above 6° some improvement in slope is evident for the very
high Mach numbers. As noted in reference 1, data obtained from
tests on other models, some at higher Reynolds numbers, indicate
similar improvement in flap performance at comparatively large
flap deflections.

The variations with Mach number of the slopes $\partial c_l/\partial\alpha$ and $\partial c_l/\partial\delta$, measured near zero lift in figures 4 and 5, are shown in figure 6. Values for the NACA 16-009 airfoil are included for comparison. These slopes result in the variation with Mach number of flap effectiveness $\partial\alpha/\partial\delta$ shown in figure 7.

Figure 6 shows that the lift parameters for the NACA 0009-64 airfoil were greater and varied more rapidly with Mach number than those for the NACA 16-009 airfoil throughout the speed range. The lower lift-curve slopes for the NACA 16-009 airfoil are believed to be associated with its larger trailing-edge angle (reference 6). Reference 7 shows that the unusually low values of $\partial c_l/\partial\delta$ and $d\alpha/\partial\delta$ for the NACA 16-009 airfoil may possibly be caused by the larger trailing-edge angle in the presence of an open gap. Low-speed data correlations show that, for plain flaps with sealed gaps, the value of $\partial\alpha/\partial\delta$ is less affected by alteration of trailing-edge angle alone. (See reference 8.)

As shown in figure 7, the NACA 0009-64 airfoil near zero lift had a flap effectiveness of about 0.48 at a Mach number of 0.4; the effectiveness decreased to a value of 0.34 at a Mach number of 0.83. It should be noted that these values are valid only for lift coefficients very near zero lift. Included in this figure is a value of elevator effectiveness obtained in the Langley Stability Research Division by an empirical method based on data from tests at Mach numbers near 0.1 and at Reynolds numbers which were higher than those obtained in the present investigation.

The marked changes in lift characteristics that occurred within 0.025 of the highest Mach numbers were influenced by tunnel-wall effects since the speeds were near choking values, but they illustrate the nature of the variations to be expected.

Pitching Moment

Variations in the quarter-chord pitching-moment coefficient with Mach number for constant angular conditions are shown in figure 8. The effect of compressibility on the variations of airfoil section pitching-moment coefficient with lift coefficient for a constant flap deflection and for a constant angle of attack is shown in figures 9 and 10, respectively. In order to indicate center-of-pressure shifts with Mach number, the parameters $\left(\dfrac{\partial c_{m_{c/4}}}{\partial c_l}\right)_\delta$ and $\left(\dfrac{\partial c_{m_{c/4}}}{\partial c_l}\right)_\alpha$ were plotted in figures 11 and 12.

Hinge Moment

The effect of compressibility on the flap section hinge-moment
coefficient for constant angular conditions is presented in figure 13.
The variations of hinge-moment coefficient with angle of attack and
with flap deflection are shown in figures 14 and 15, respectively.
The curves in these two figures indicate that, in certain ranges of
flap deflection, changes in speed may produce irregular variations
in stick force and even stick-force reversals. The variations with
Mach number of $\partial c_h/\partial \alpha$ and $\partial c_h/\partial \delta$ for $\alpha = 0^\circ$, $\delta = -0.1^\circ$ are
given in figure 16. These slopes apply over a very limited range of
angle of attack and flap deflection, as is evident from figures 14
and 15. Figures 13 and 15 show that, at the higher flap angles,
marked changes in the hinge-moment characteristics occurred in the
speed range above $M = 0.7$. Pressure-distribution data and schlieren
flow photographs obtained in the Langley rectangular high-speed tunnel
in investigations of other flapped airfoils have shown that abrupt
changes in hinge-moment characteristics occurred when the critical
speed was exceeded. These effects arose from the passage of shock
waves across the flap.

Included in figure 16 for comparison with the results of the
tests are estimated values of $\partial c_h/\partial \alpha$ and $\partial c_h/\partial \delta$ obtained from
empirical methods presented in reference 8. Comparison of the hinge-
moment parameters for the two airfoils at the lowest test speed
$(M = 0.4)$ showed qualitatively the effect of changes in trailing-edge
angle as expected from low-speed research. However, the difference
in Reynolds number and Mach number between the empirically established
data and the test data prevents a direct quantitative comparison.

Comparison of the rate at which the hinge-moment parameters vary
with Mach number for the subject tests and for the NACA 16-009
airfoil model (trailing-edge angle = 22°) showed that the model
with the smaller trailing-edge angle had much less rapid change
in the hinge-moment slopes $\partial c_h/\partial \alpha$ and $\partial c_h/\partial \delta$. References 9 and 10,
tests of full-scale three-dimensional tail surfaces with sealed
and 0.005c gaps and for smaller trailing-edge angles (12° and 13°),
show that there was only slight variation in $\partial c_h/\partial \alpha$ with Mach
number and that $\partial c_h/\partial \delta$ increased negatively. These results
suggest the possibility of controlling the variation of $\partial c_h/\partial \delta$
or $\partial c_h/\partial \alpha$ with Mach number through proper selection of the
trailing-edge angle. More high-speed data are needed to show the
effects of associated flap-shape parameters before selection of
the desired trailing-edge angles for a particular design can be made.

CONCLUSIONS

The results of the present high-speed wind-tunnel investigation of a 5-inch-chord NACA 0009-64 airfoil having a 33.4-percent-chord flap with a nose overhang of 20.1 percent of the flap chord and a 0.017-percent-chord unsealed gap can be summarized as follows:

1. The elevator-effectiveness factor $\partial\alpha/\partial\delta$ for small angle-of-attack and flap-angle increments was 0.43 at a Mach number of 0.4 but decreased to a value of 0.34 at a Mach number of 0.83.

2. At subcritical speeds the rate of change of hinge-moment coefficient with both angle of attack and flap deflection $(\partial c_h/\partial\alpha)_\delta$ and $(\partial c_h/\partial\delta)_\alpha$ showed increasing balance with increasing Mach number. At supercritical speeds abrupt and large variations in hinge-moment characteristics occurred.

3. Comparison of the results of the present investigation with previous results for the NACA 16-009 flapped airfoil shows that $(\partial c_l/\partial\alpha)_\delta$ and $(\partial c_l/\partial\delta)_\alpha$ for the NACA 0009-64 flapped airfoil (trailing-edge angle = 16°) were larger and increased more rapidly with Mach number than for the NACA 16-009 airfoil (trailing-edge angle = 22°). The hinge-moment parameters $(\partial c_h/\partial\alpha)_\delta$ and $(\partial c_h/\partial\delta)_\alpha$ were less affected by Mach number for the NACA 0009-64 airfoil than for the NACA 16-009 airfoil.

4. The possibility that the trailing-edge angle may be used to control the variation of $(\partial c_h/\partial\delta)_\alpha$ or $(\partial c_h/\partial\alpha)_\delta$ with Mach number is shown.

Langley Memorial Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Field, Va., October 8, 1946

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      Tunnel Tests of an NACA 16-009 Airfoil Having a 33-Percent-
      Chord Flap with an Overhang 21 Percent of the Flap Chord.
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10. Schueller, Carl F., Korycinski, Peter F., and Strass, H. Kurt:
      Tests of a Full-Scale Horizontal Tail Surface in the Langley
      16-Foot High-Speed Tunnel. NACA TN No. 1074, 1946.

Figure 1.- Langley 24-inch high-speed tunnel test section with
model mounted in balance.
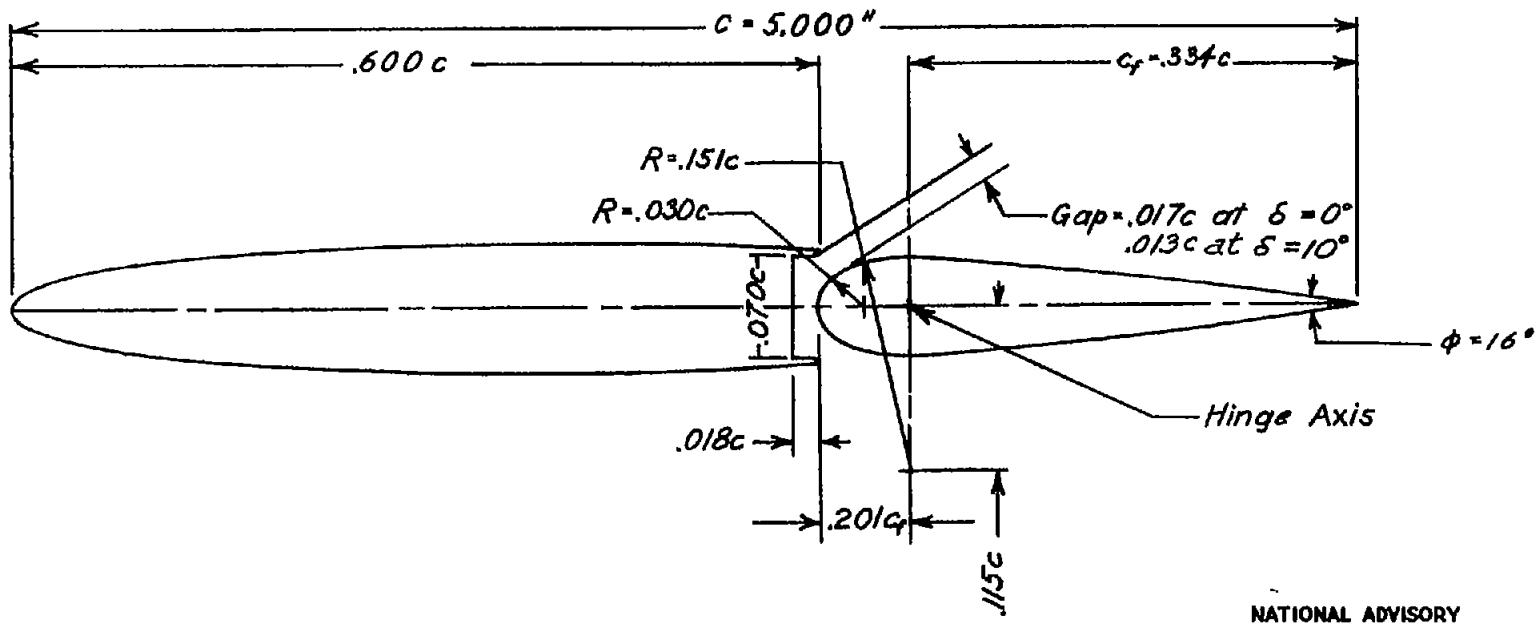
Figure 2. – NACA 0009-64 airfoil with a 0.334c flap having a 0.201c_f nose overhang.

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(a) $\alpha = -4°$.
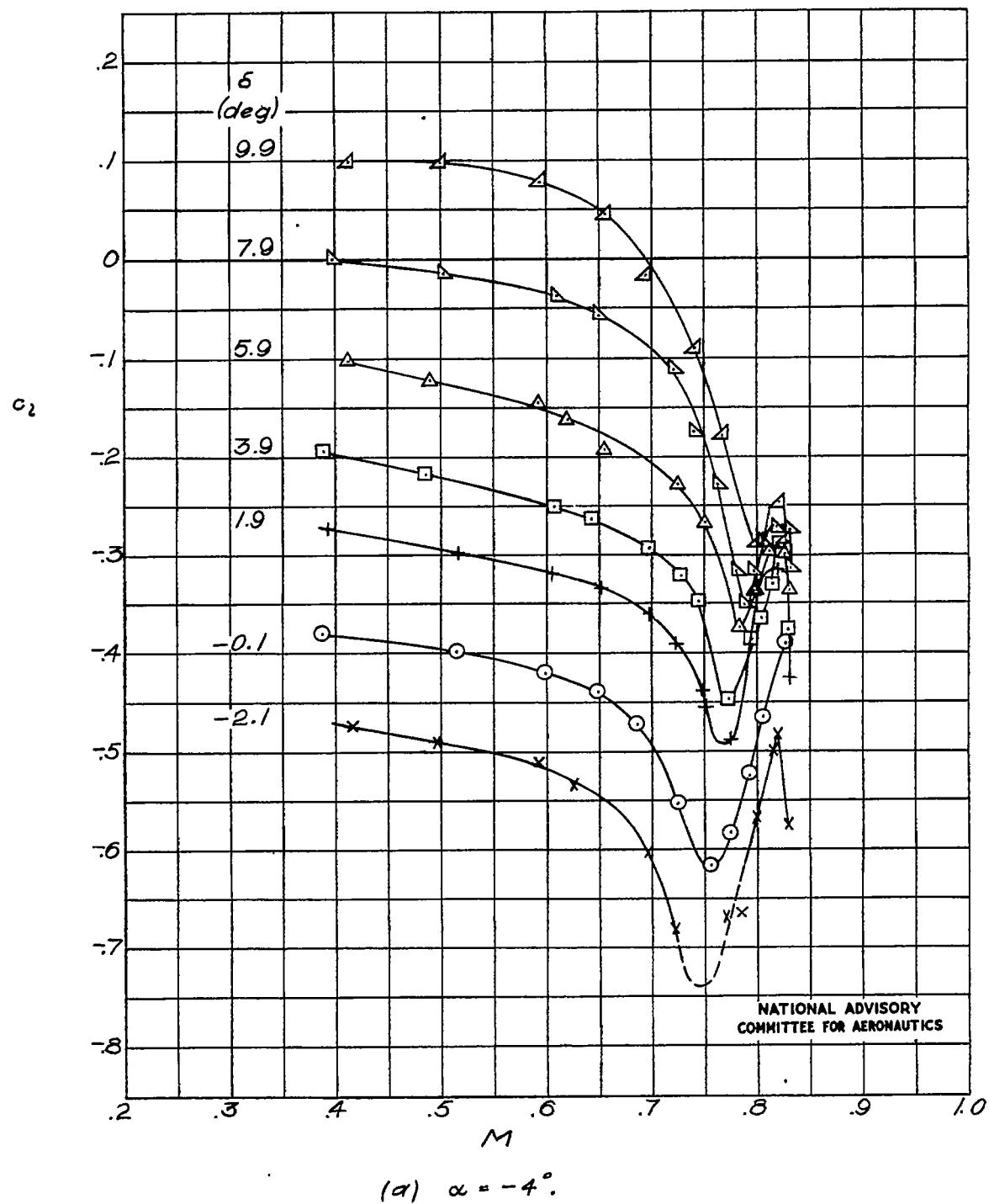
Figure 3.- Variation of section lift coefficient with Mach number.
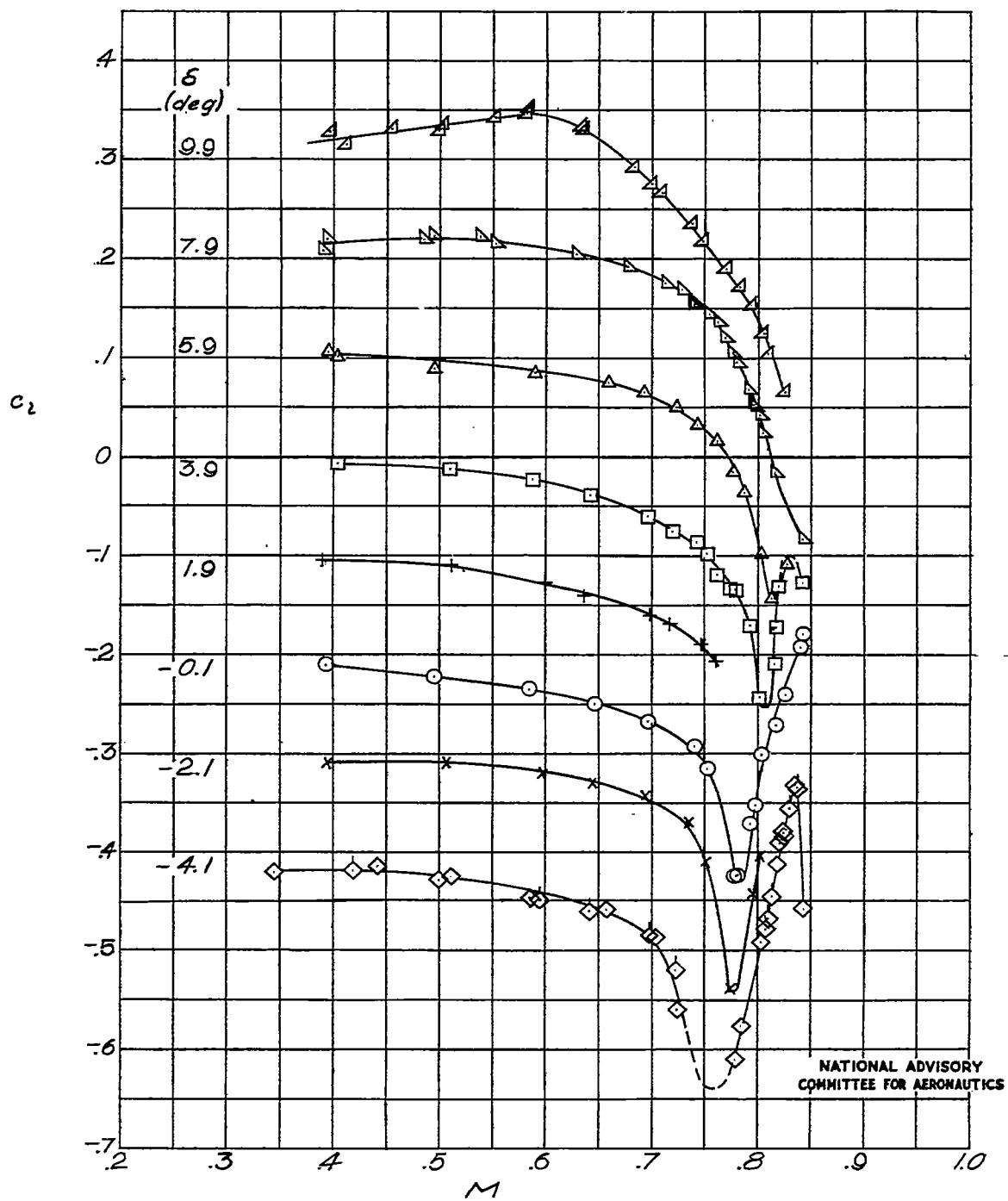
(b) $\alpha = -2°$.

Figure 3.- Continued.

(c)   α = 0°
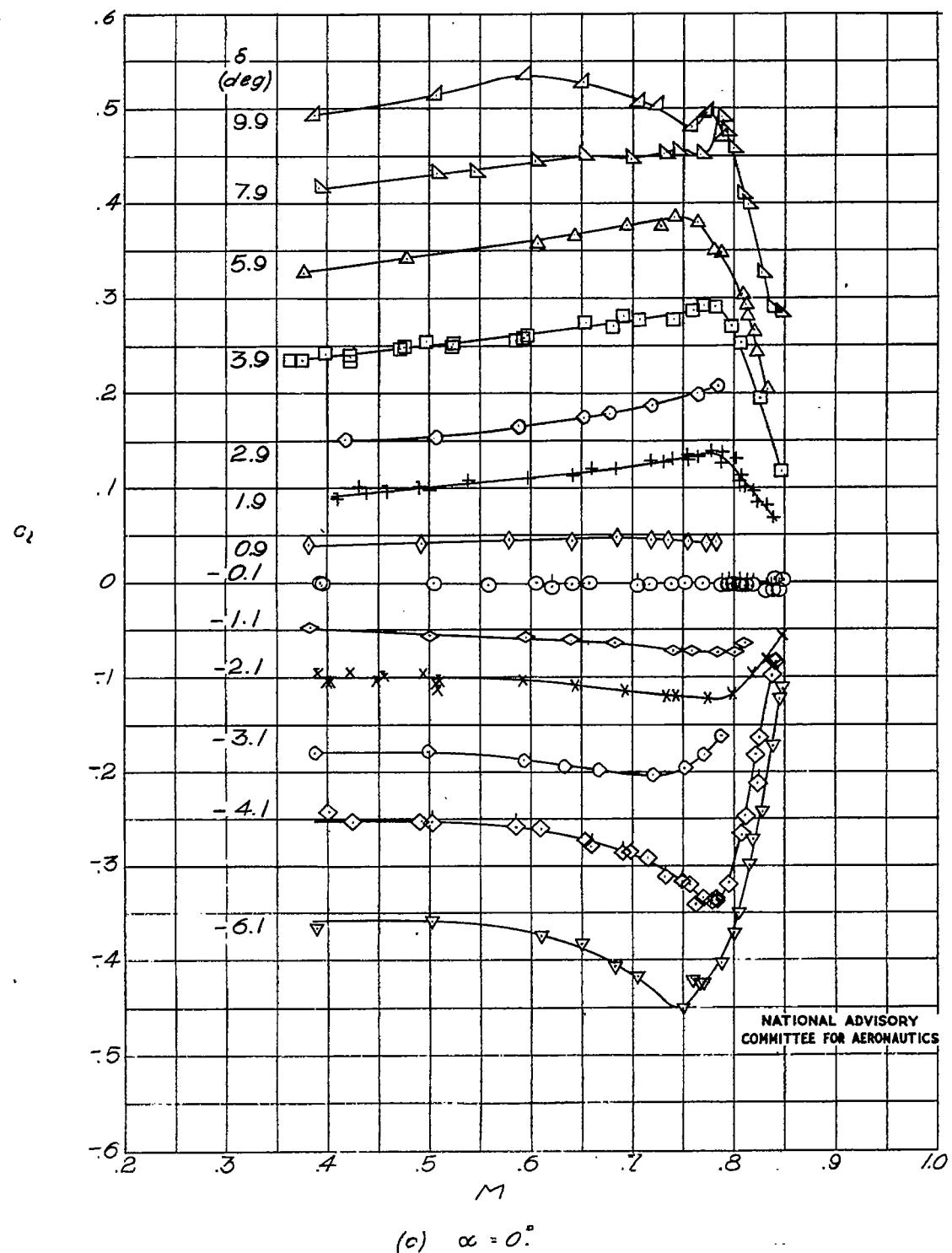
Figure 3. - Continued.
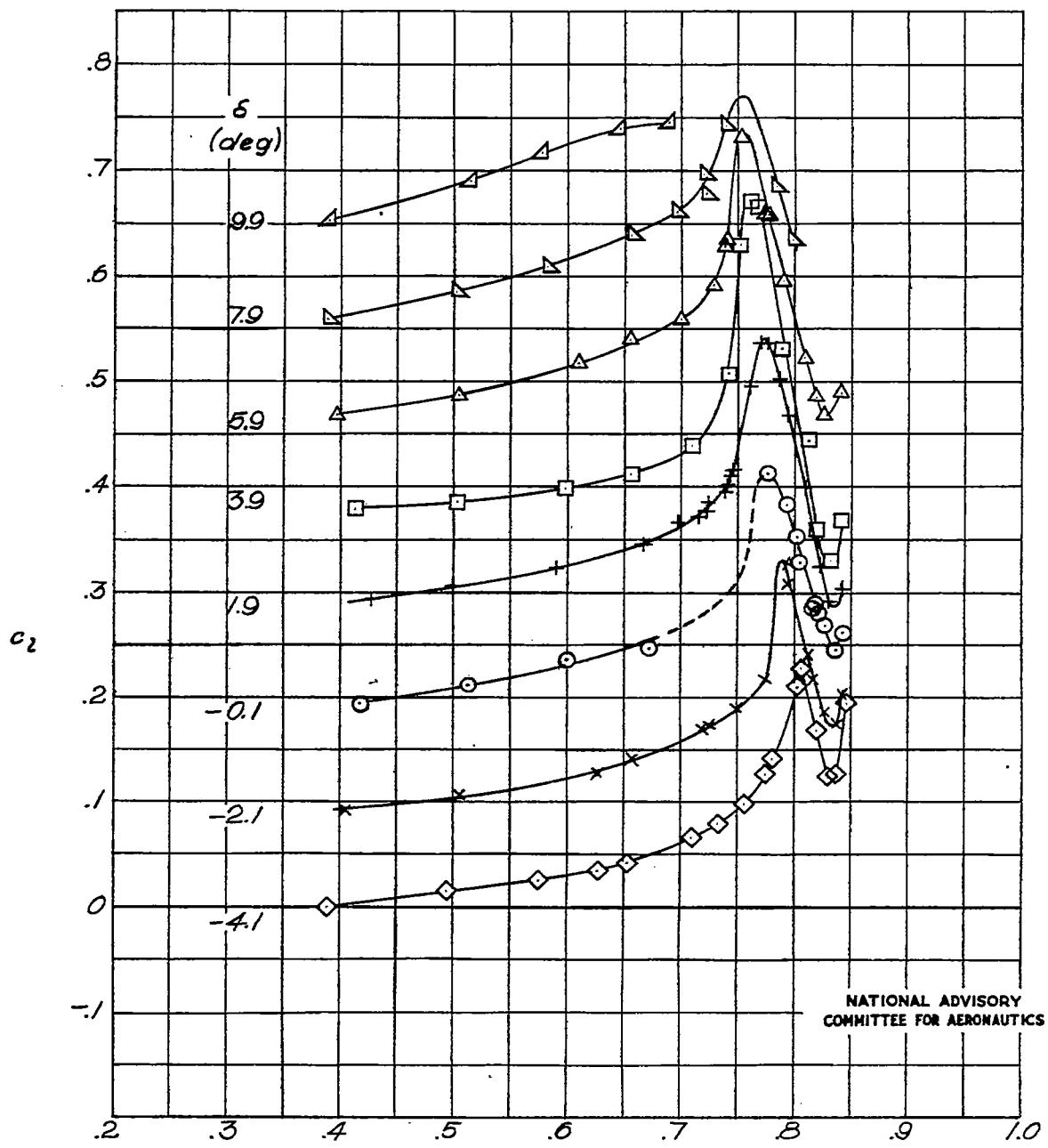
(d) $\alpha = 2°$.

Figure 3. - Concluded.
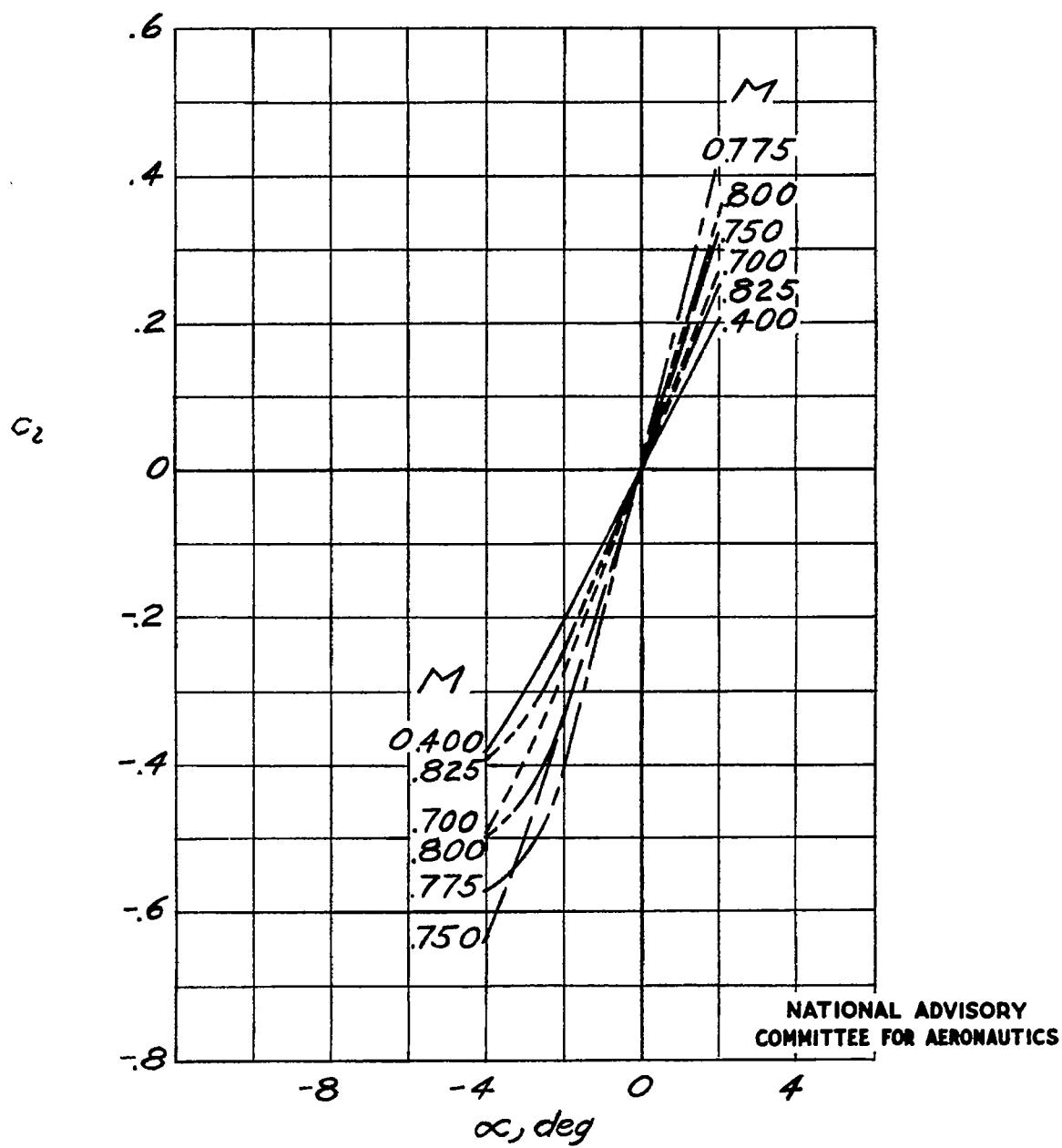
Figure 4. – Variation of section lift
coefficient with angle
of attack. δ = -0.1°.
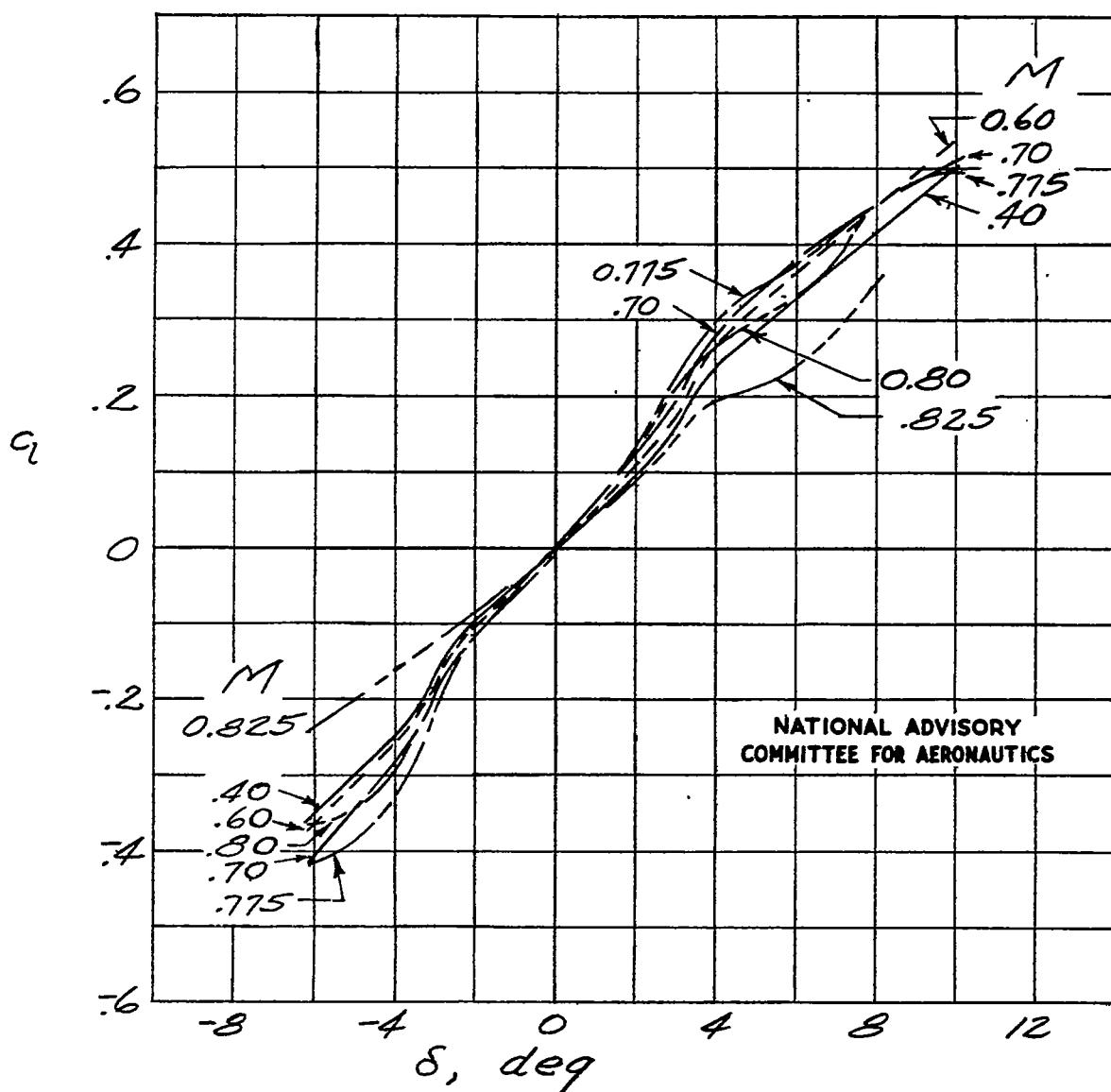
Figure 5. – Variation of section lift
coefficient with flap deflection.
$\alpha = 0°$.
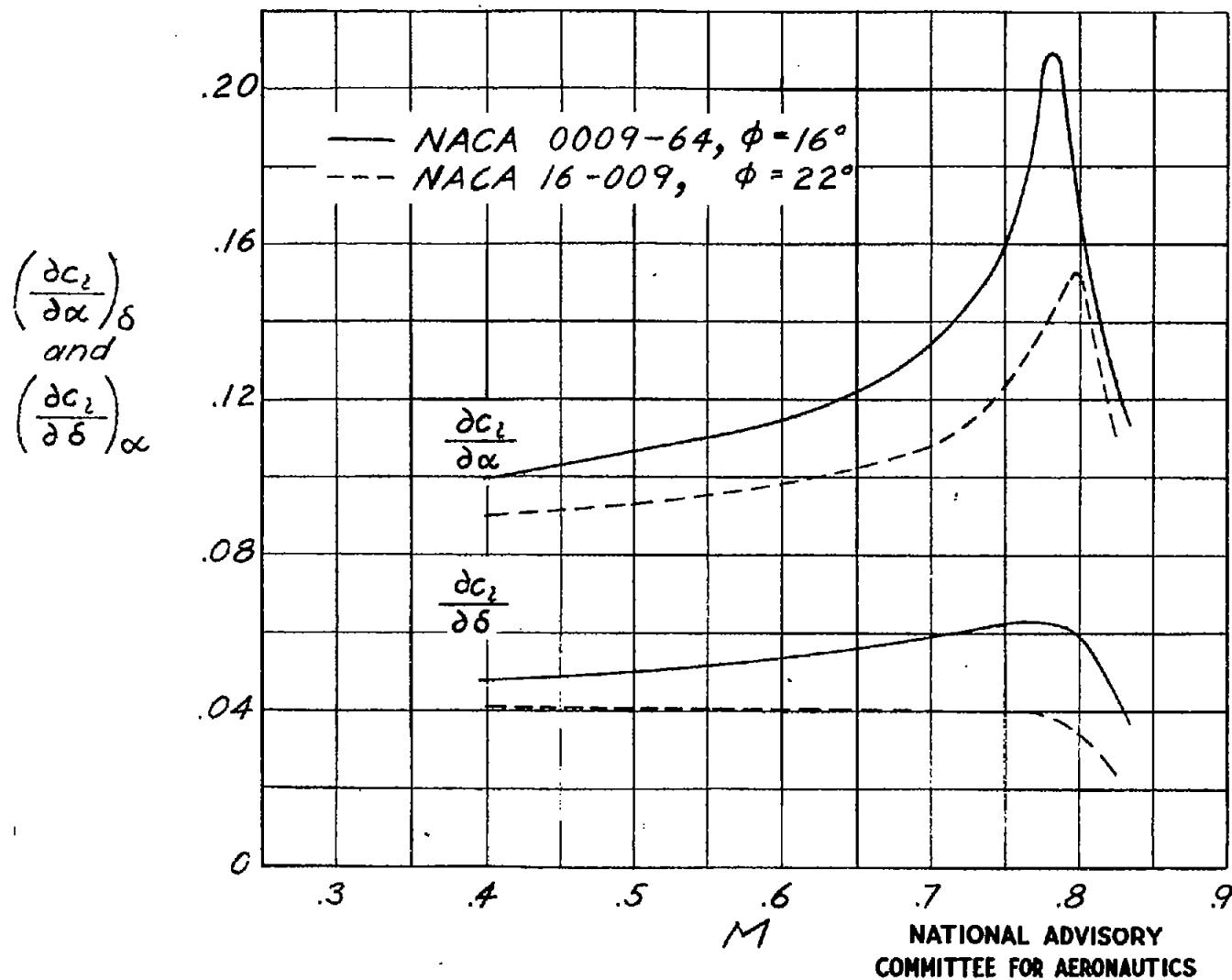
Figure 6. - Variation of lift curve slopes with Mach number.
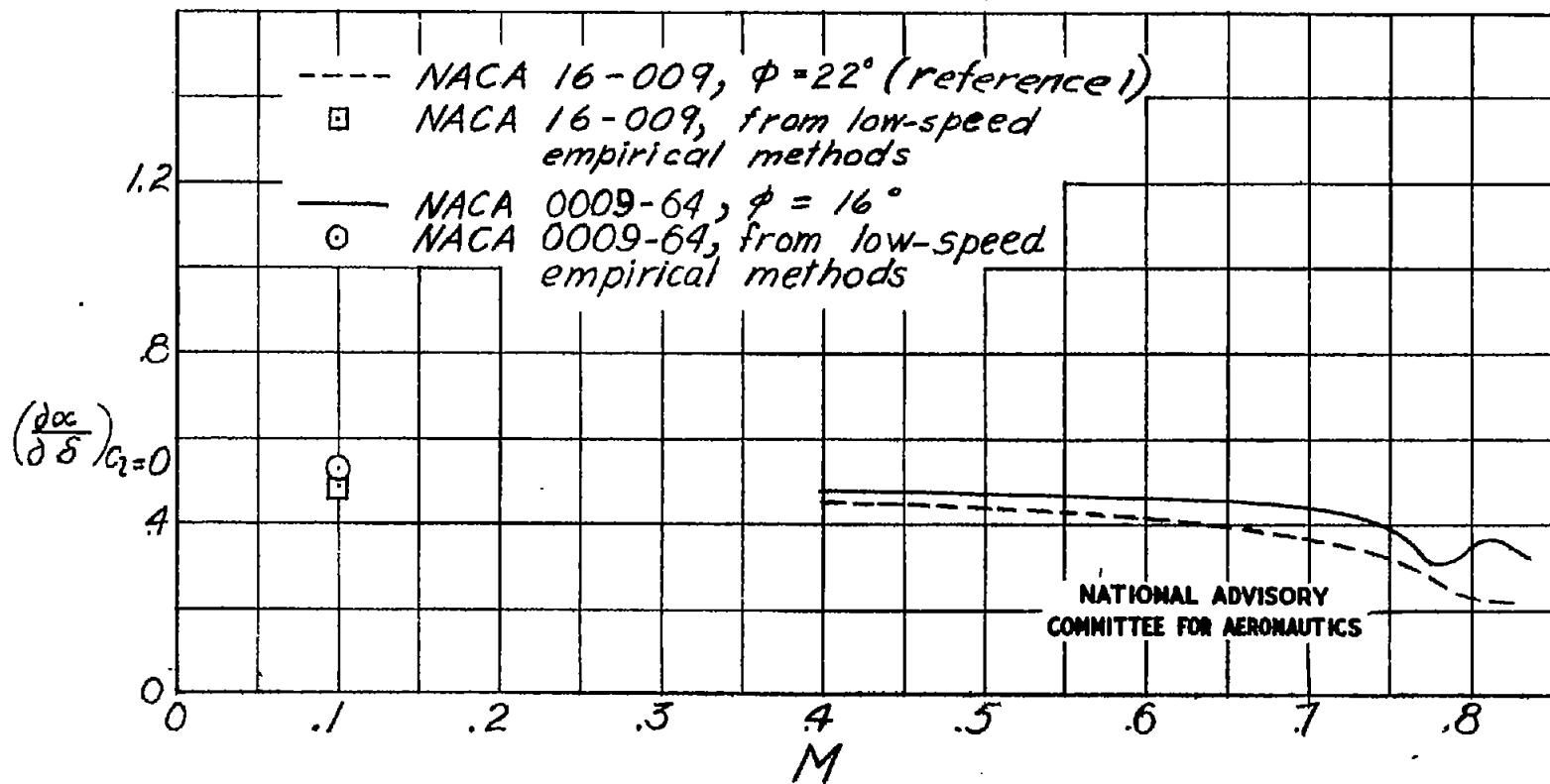
Figure 7. - Variation of flap effectiveness with Mach number.
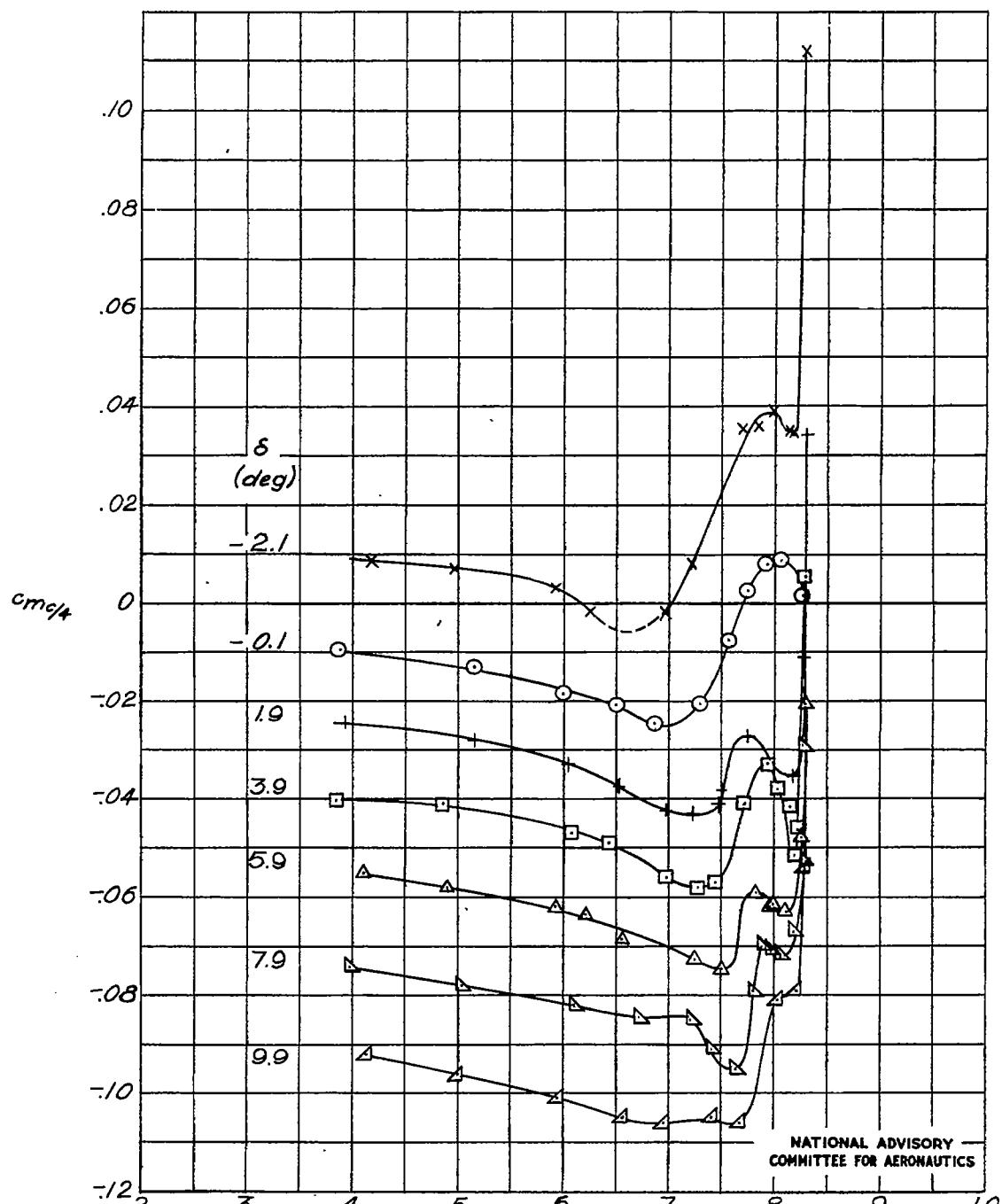
(a) $\alpha = -4°$

Figure 8. - Variation of section quarter-chord moment coefficient with Mach number.
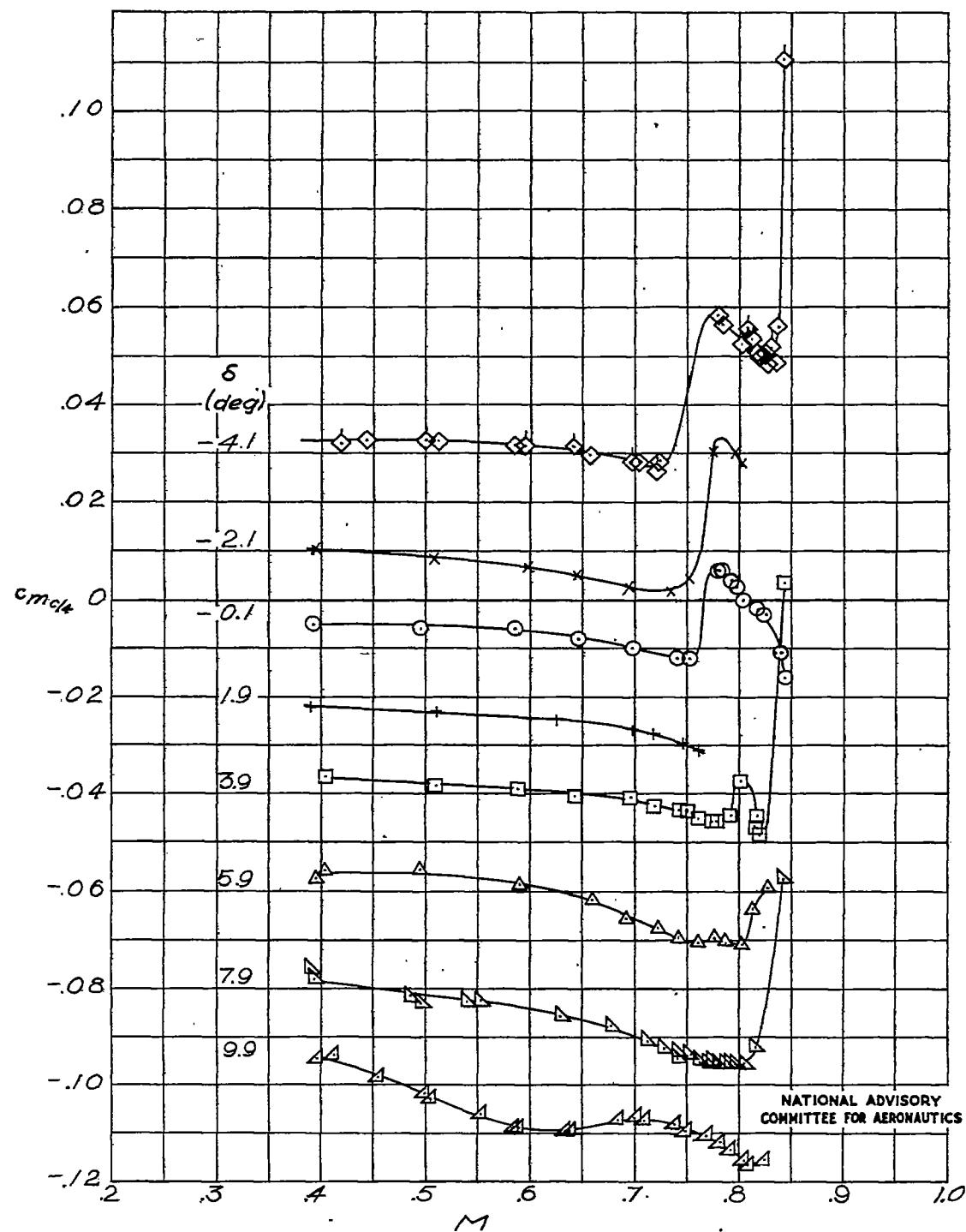
(b) $\alpha = -2°$.

Figure 8. — Continued.

(c) α = 0°.

Figure 8. - Continued.

(d) $\alpha = 2°$
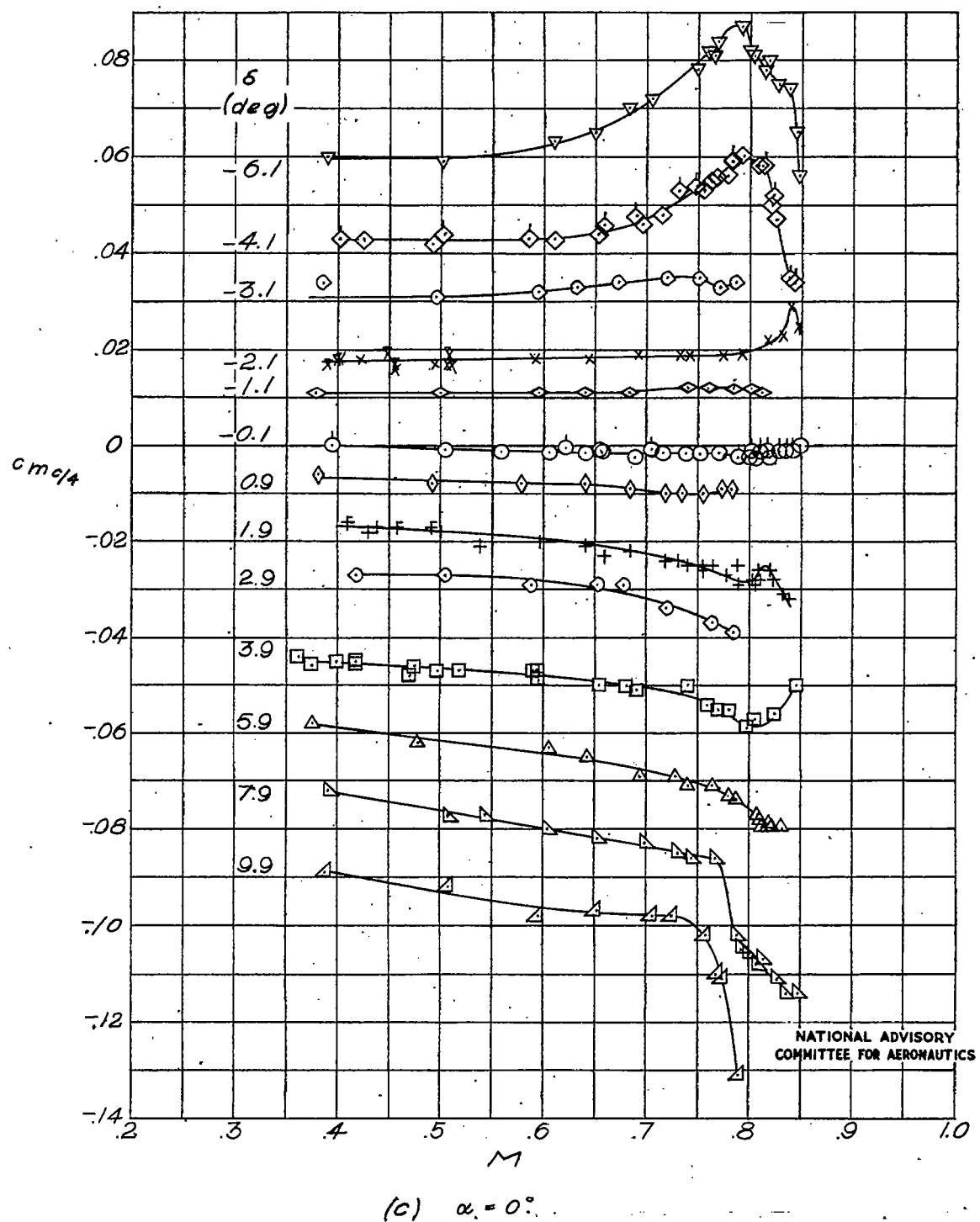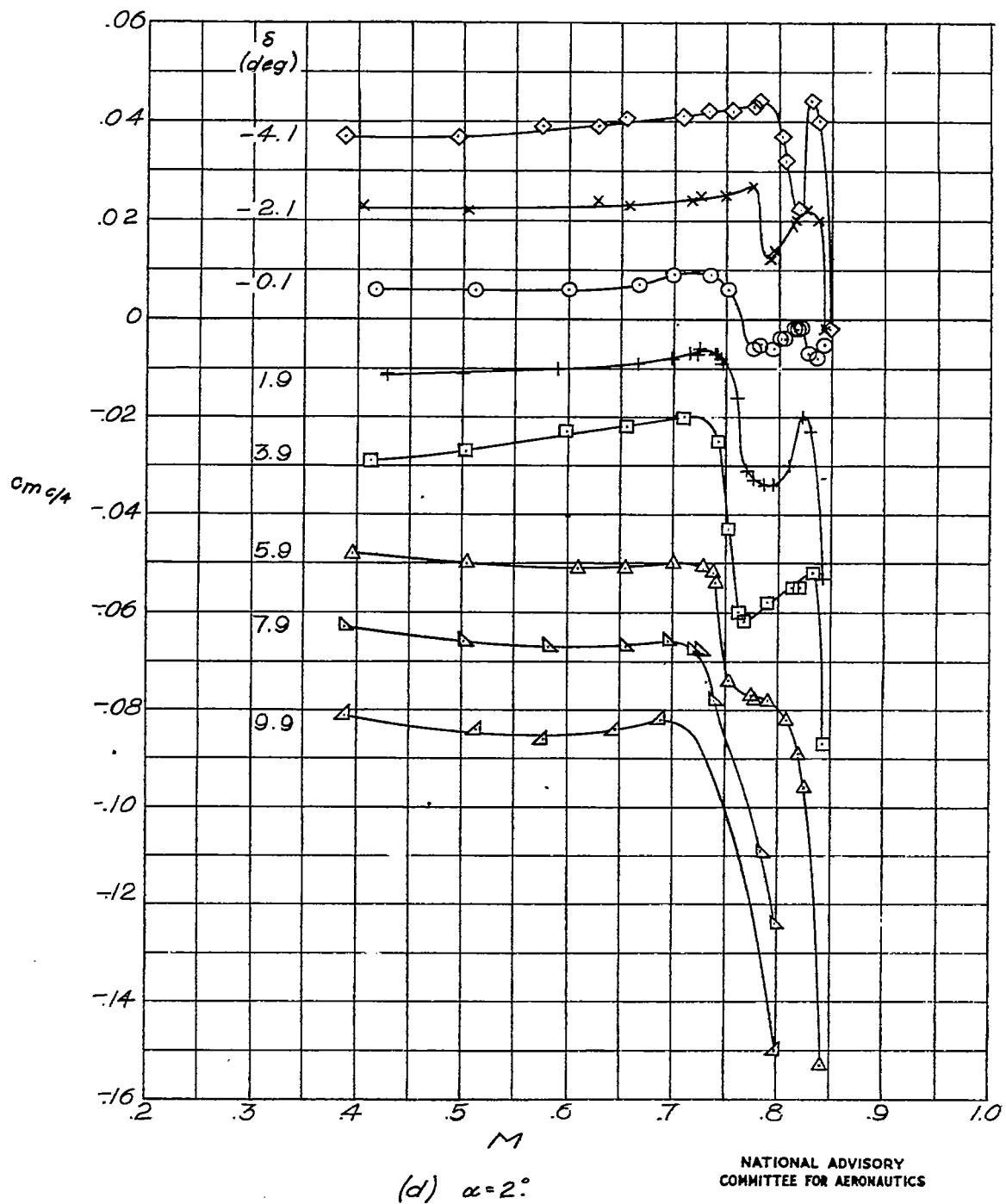
Figure 9. - Concluded.
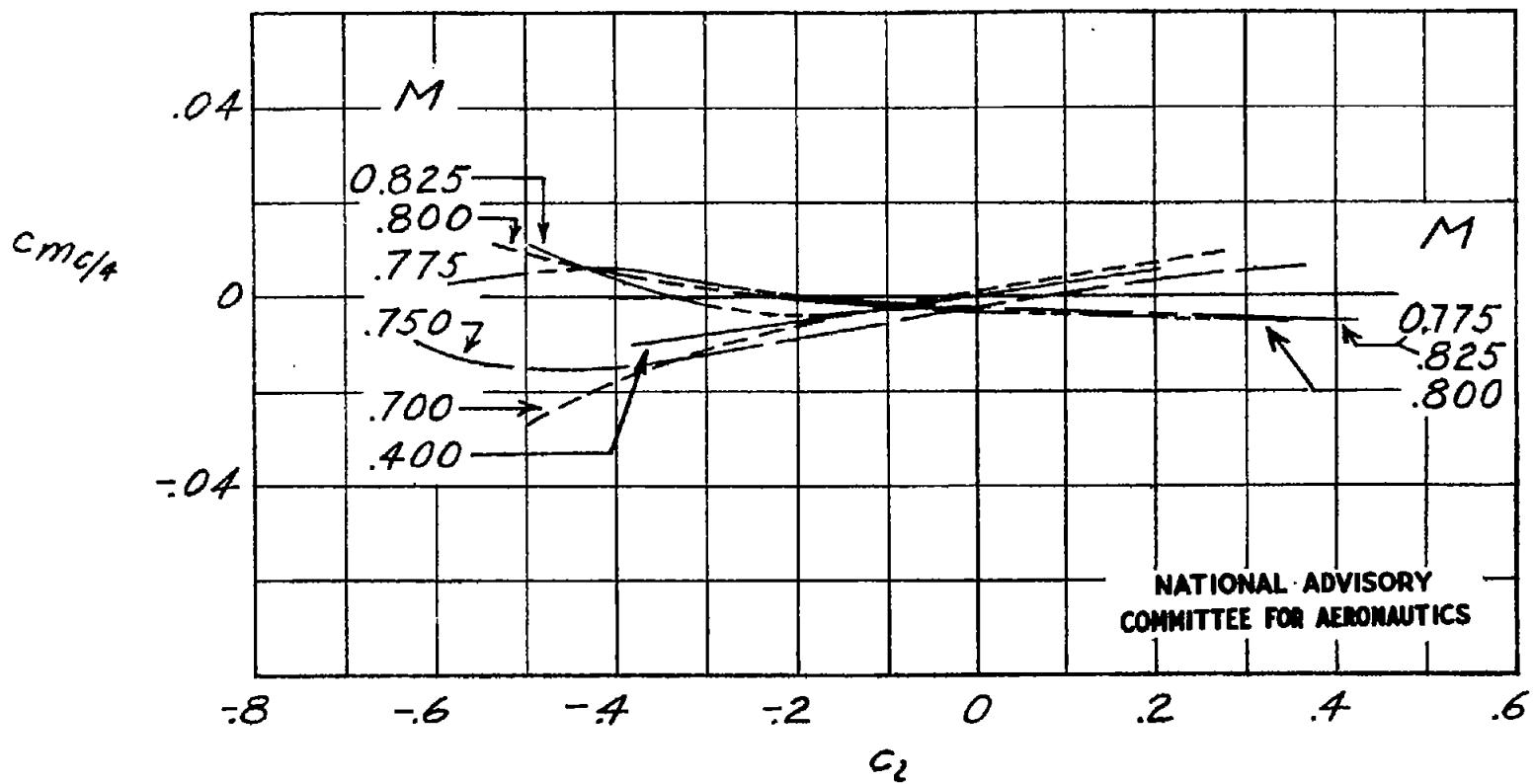
Figure 9. - Variation of section quarter-chord
moment coefficient with section
lift coeffient. $\delta = -0.1°$.
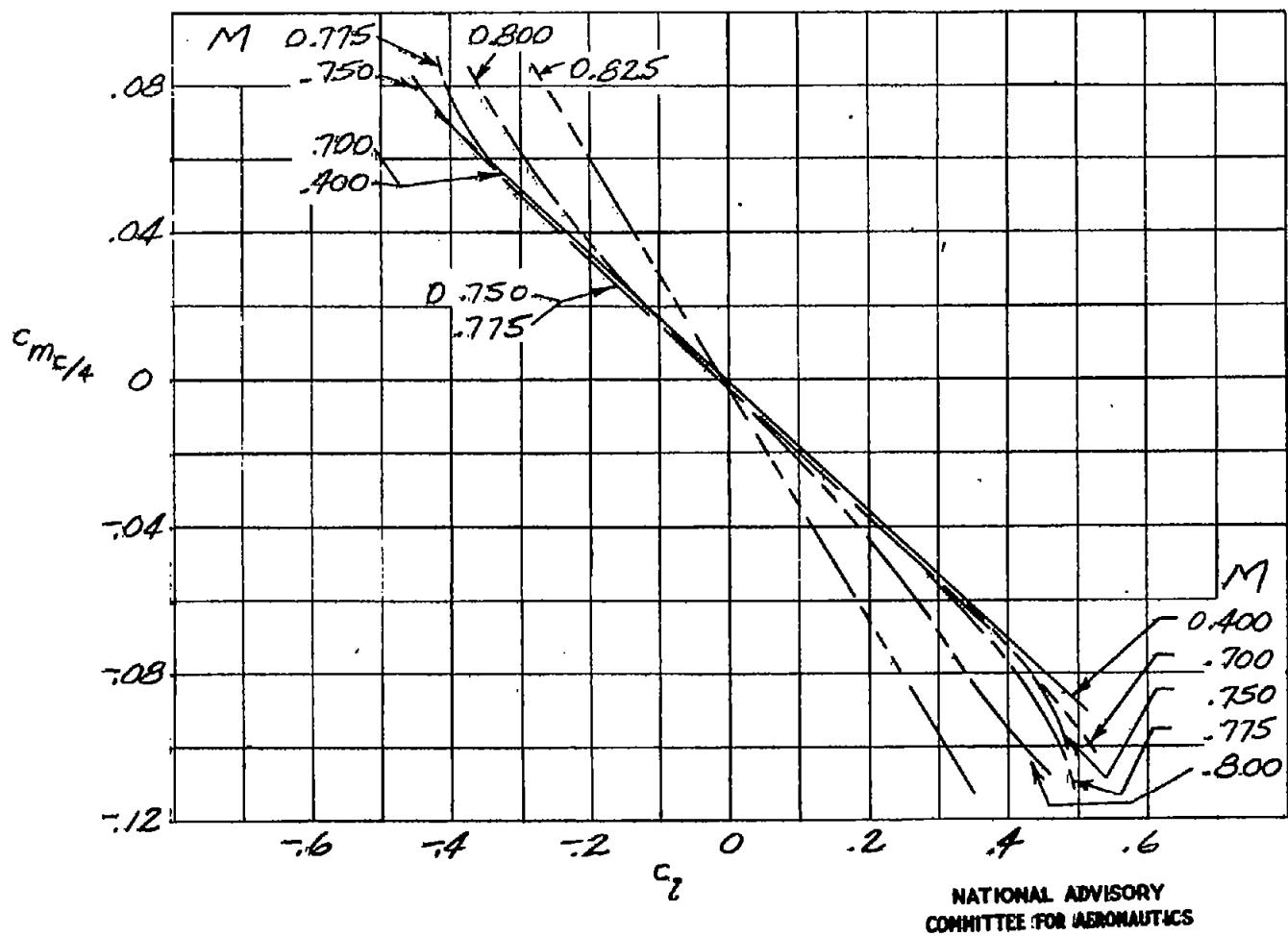
Figure 10.- Variation of section quarter-chord
moment coefficient with section lift
coefficient for a constant angle
of attack. $\alpha = 0°$.
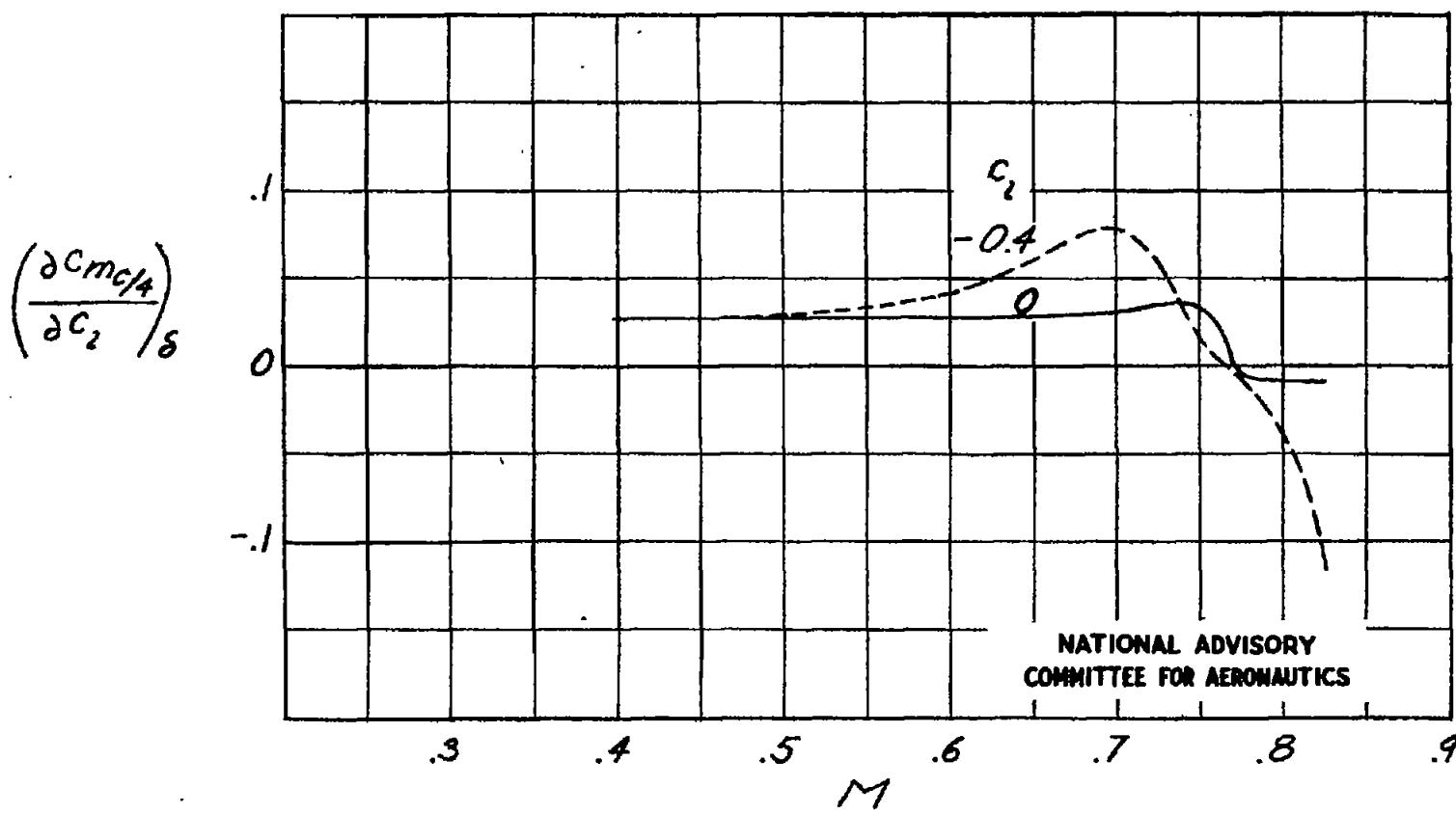
Figure 11.— Variation with Mach number of the rate of change of airfoil section moment coefficient with section lift coefficient for a constant flap deflection. $\delta = -0.1°$.
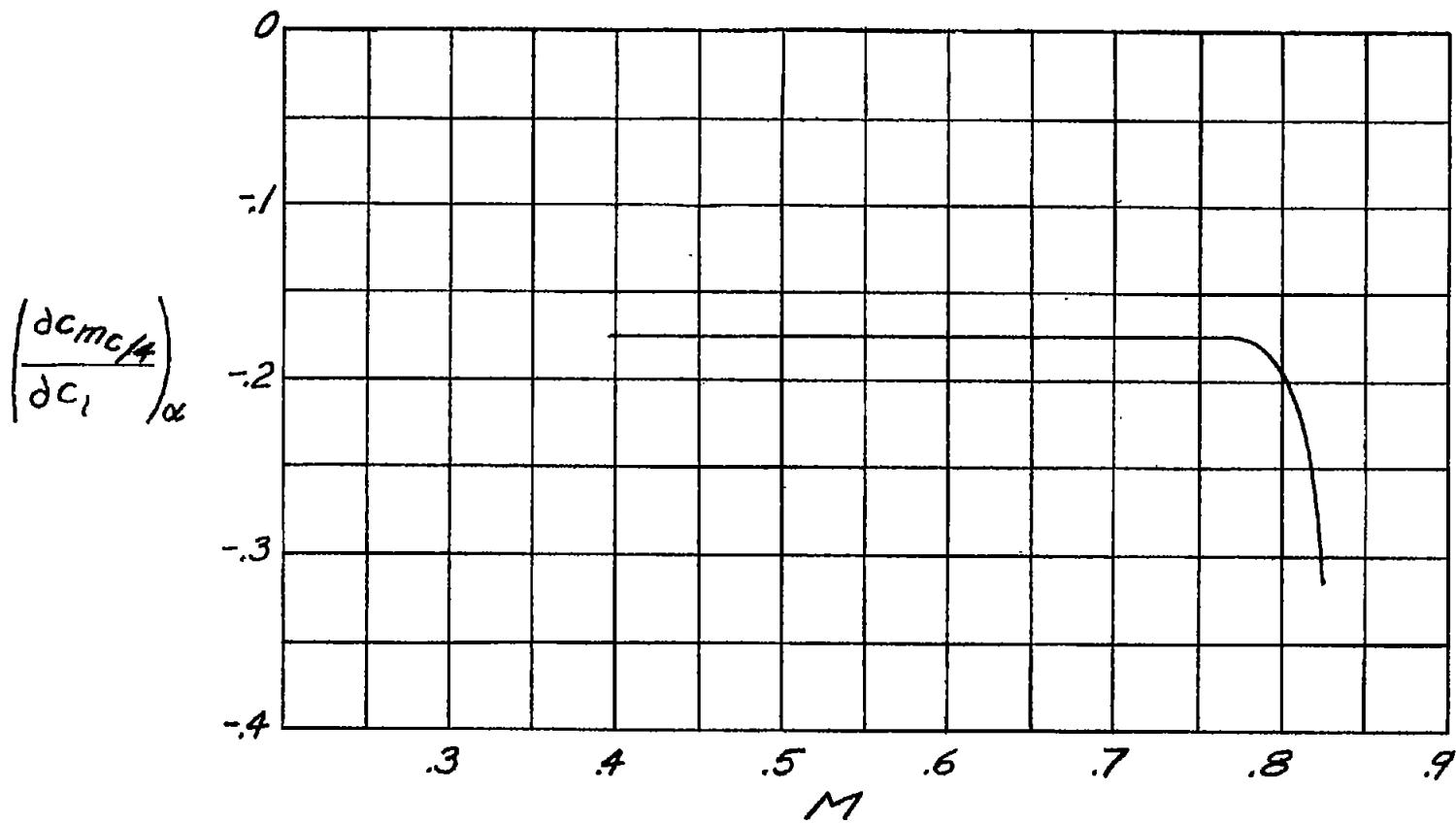
Figure 12. — Variation with Mach number of the rate of
change of airfoil section moment coefficient
with section lift coefficient for a constant
angle of attack. $\alpha = 0°$.

(a) $\alpha = -4°$
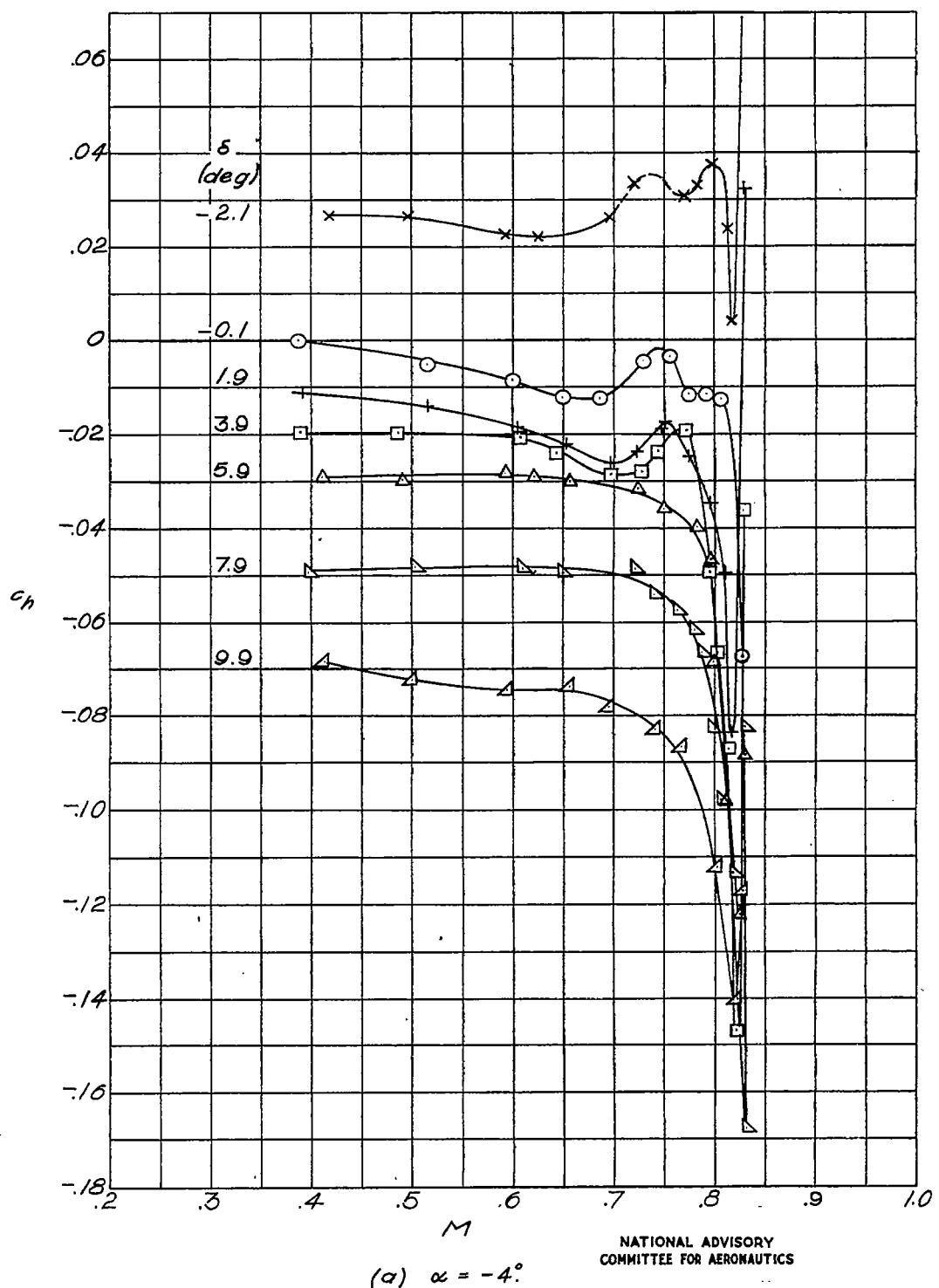
Figure 13. - Variation of flap section hinge-moment coefficient with Mach number.
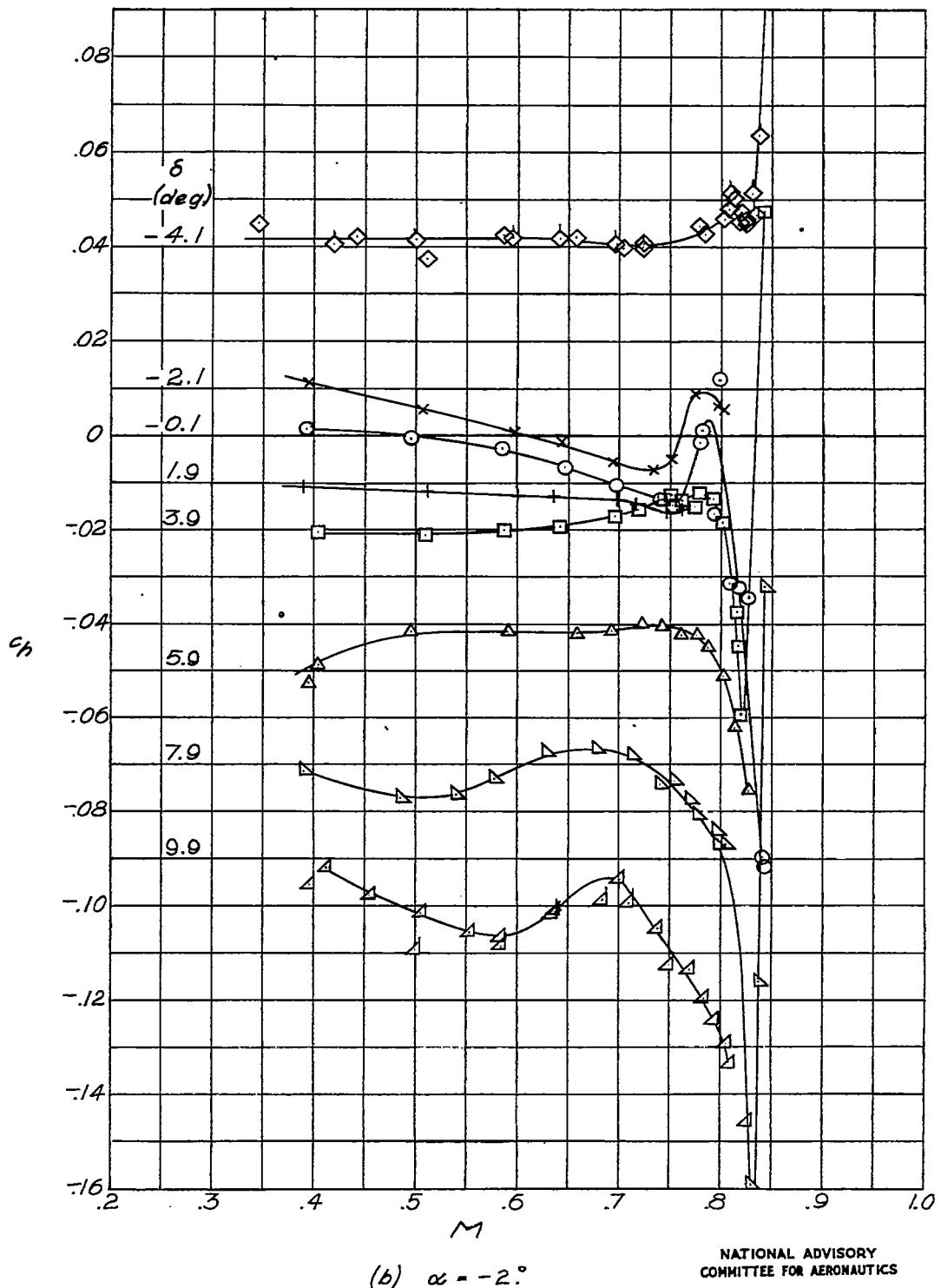
(b) $\alpha = -2°$

Figure 13. - Continued.

(c) α = 0°.

Figure 13. - Continued.

(d)   α = 2°.
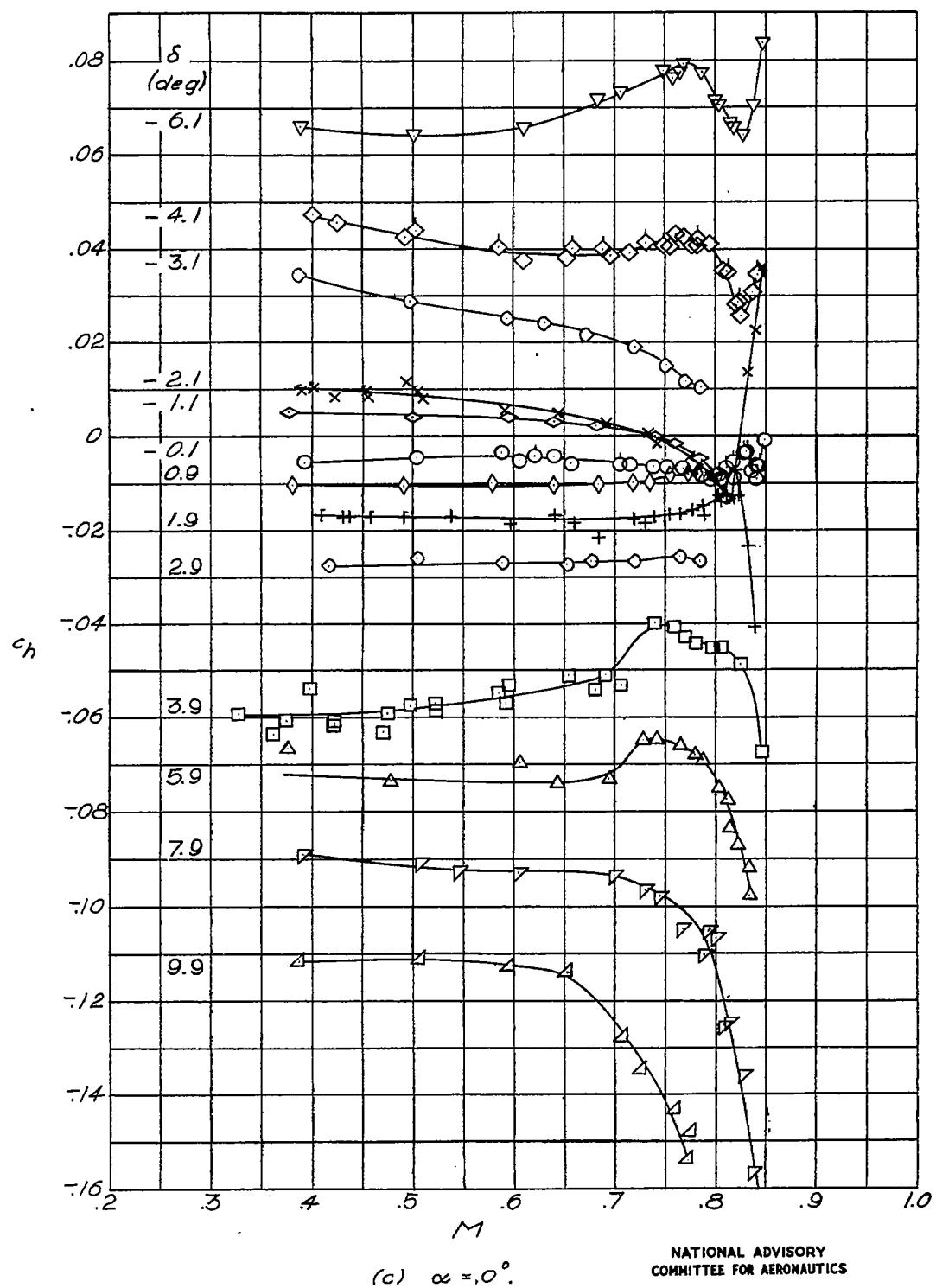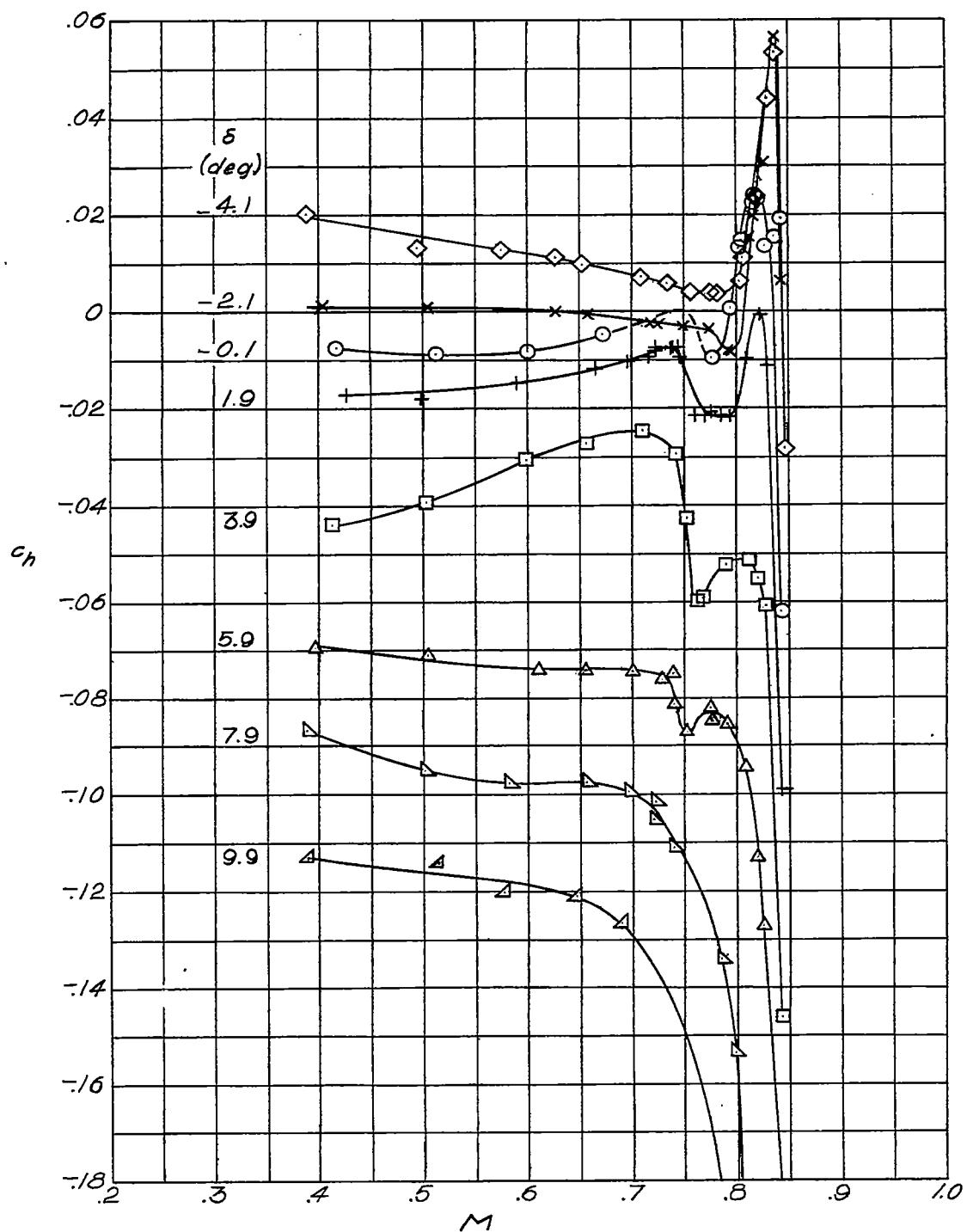
Figure 13. - Concluded.
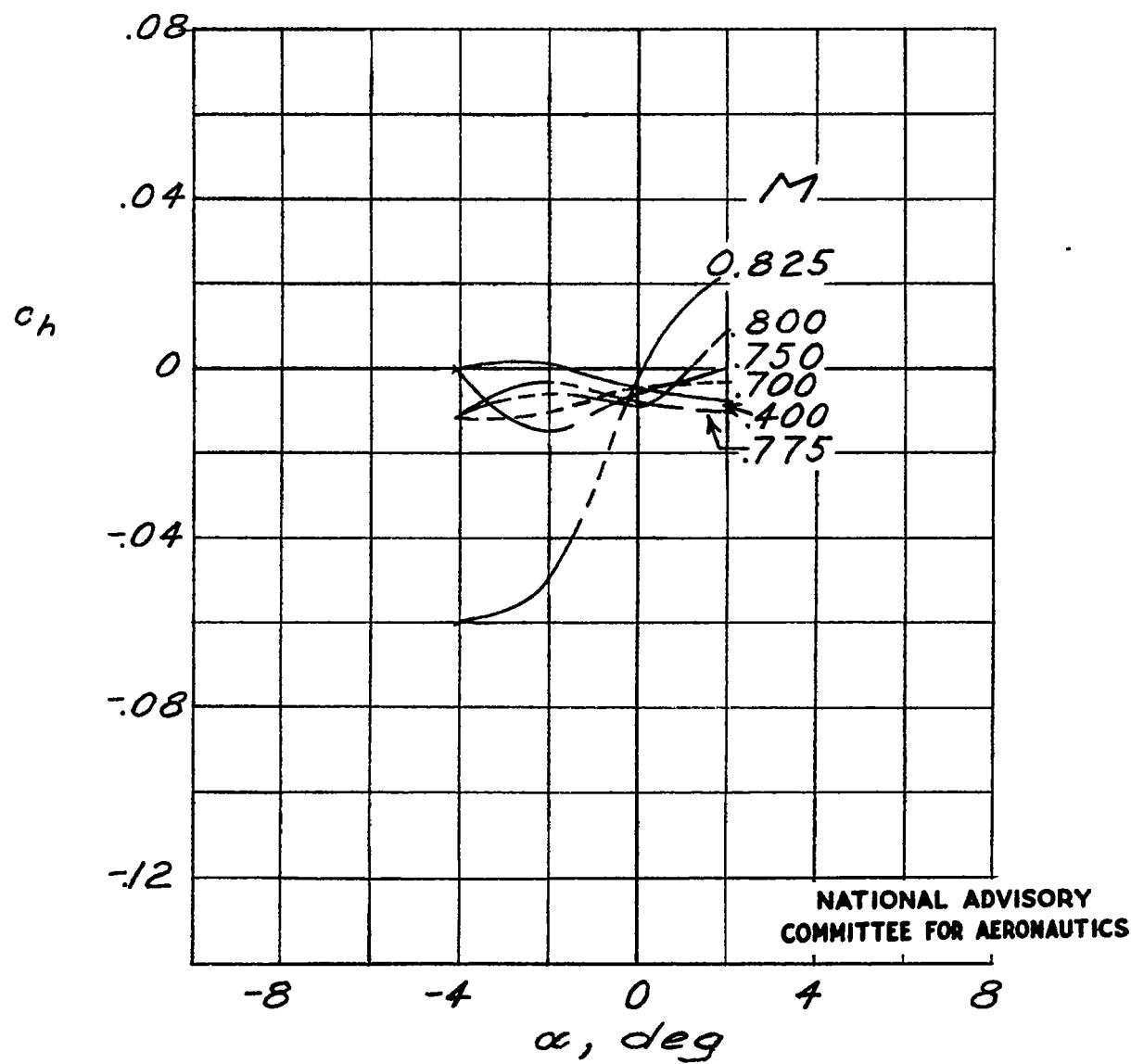
Figure 14. – Variation of flap section
       hinge – moment coefficient
       with angle of attack.
       $\delta = -0.1°$
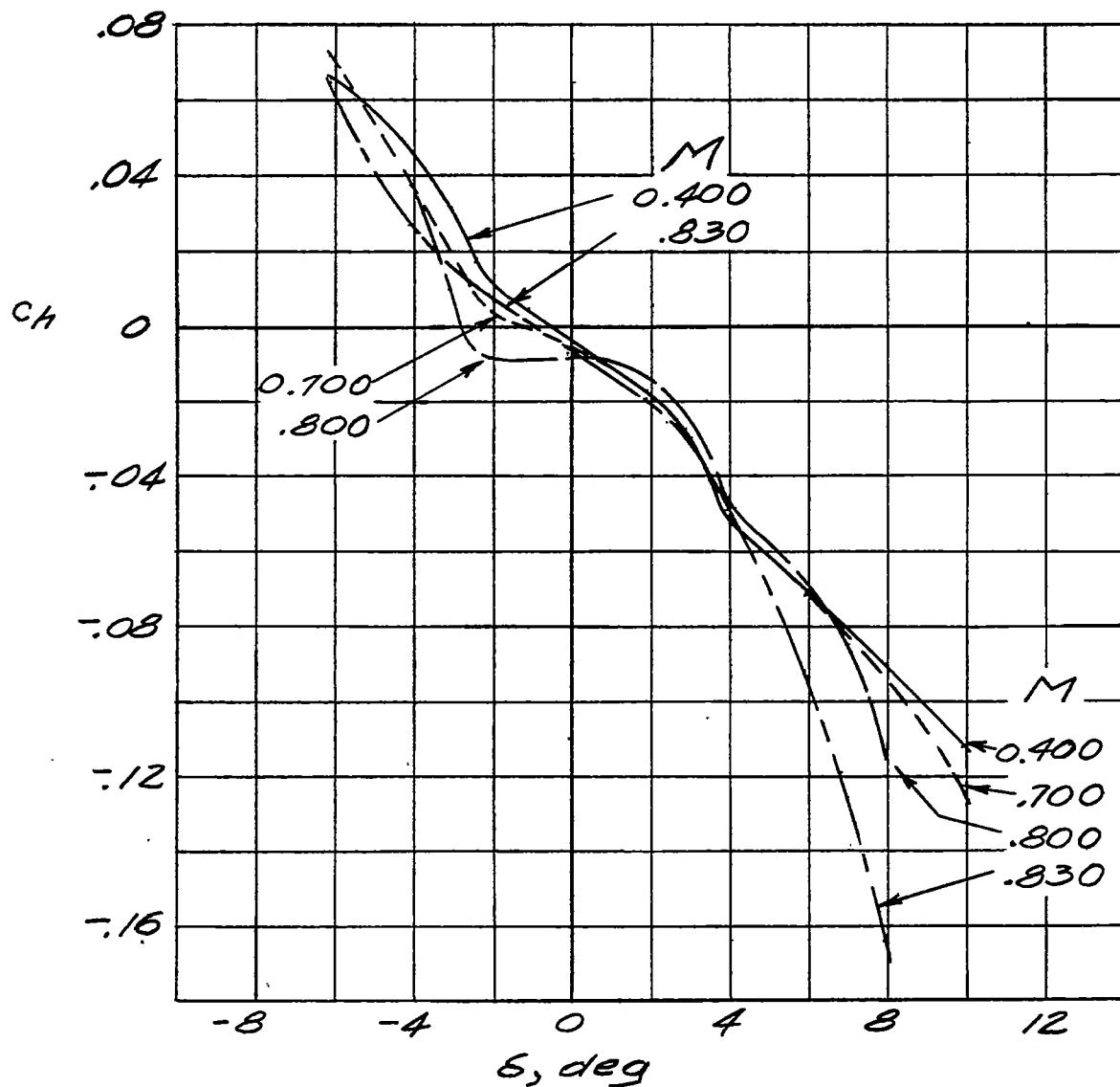
Figure 15.— Variation of flap section hinge—moment coefficient with flap deflection. α = 0°.
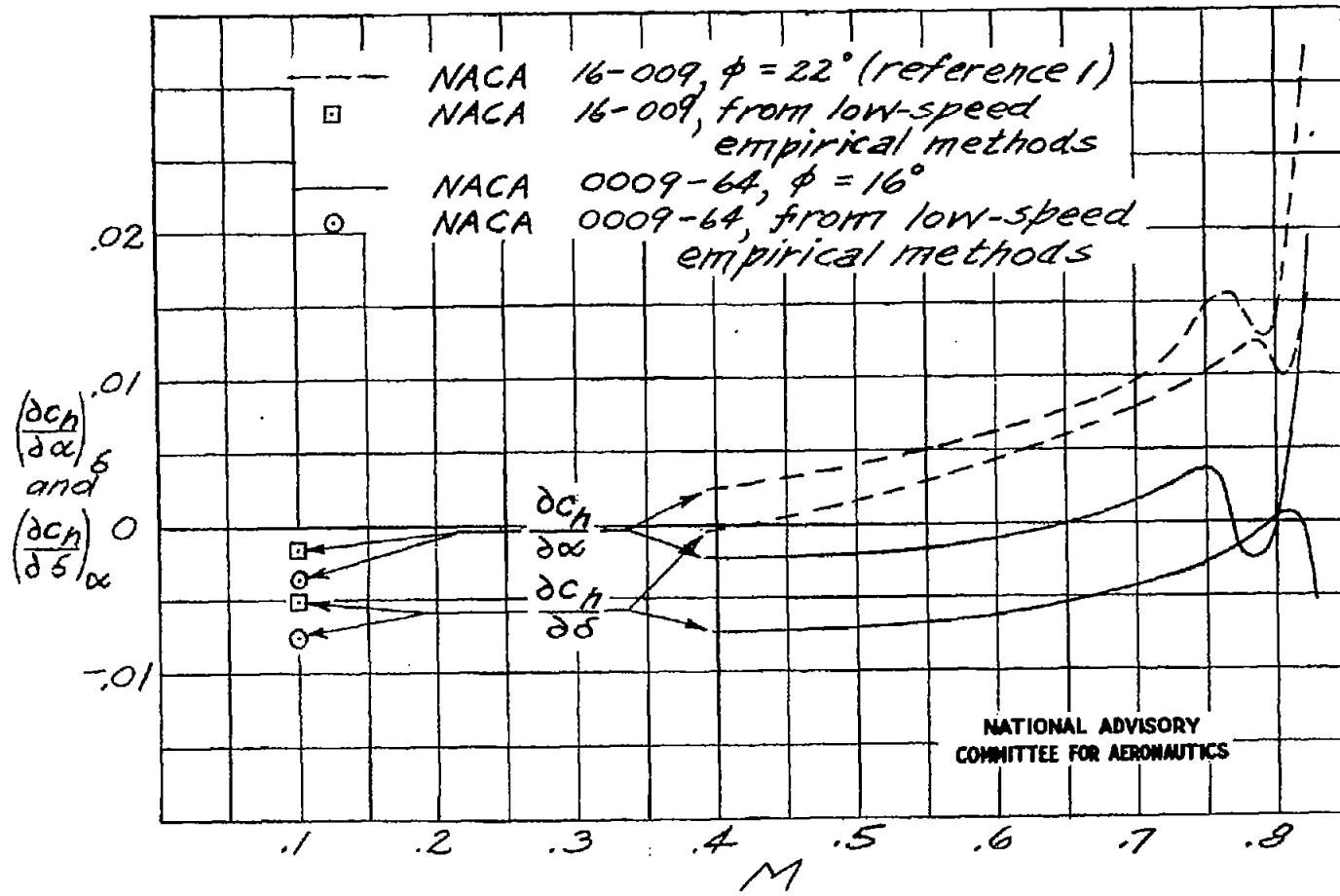
Figure 16. - Variation of hinge-moment parameters with Mach number. $\alpha = 0°$; $\delta = -0.1°$.